MORPHOMETRIC ANALYSIS AND FABRICATION OF PROSTHETIC EAR USING CAD/CAM AND ADDITIVE MANUFACTURING TECHNOLOGY

by

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ABSTRAK

Pemulihan telinga palsu adalah salah satu kaedah rawatan untuk kecacatan telinga. Amalan semasa oleh pakar memerlukan pesakit menjalani pembedahan *osseointegrated craniofacial implant* untuk mengekalkan telinga palsu pada kedudukannya. Secara tradisional, *wax pattern* dihasilkan daripada process *impression* ke atas pesakit dan telinga palsu dihasilkan daripada silicon. Kaedah konvensional ini memakan masa yang agak lama, kerja yang agak rumit dan menyebabkan ketidakselesaan kepada pesakit. Tambahan pula, ketepatan telinga palsu yang terhasil kurang memuaskan. Kaedah *impression* ini memainkan peranan yang sangat penting untuk menentukan ketepatan penghasilan semula telinga yang terjejas dan yang tidak terjejas, orientasi telinga tersebut semasa percubaan wax dan fabrikasi telinga palsu. Oleh itu, data antropometri adalah penting untuk memastikan telinga palsu berada di kedudukan dan orientasi yang betul.

Kajian ini bertujuan untuk menyediakan data morfometrik bagi beberapa standard parameter telinga bagi penduduk Kelantan dan juga menerangkan kaedah mereka bentuk dan menghasilkan telinga palsu menggunakanteknologi CAD/CAM dan pembuatan aditif. Kajian klinikal dijalankan terhadap seorang pesakit di HUSM dan perbandingan dibuat antara kaedah tradisional dengan kaedah terbantu komputer. Kajian penilaian juga dilakukan terhadap telinga palsu yang dihasilkan daripada kedua-dua kaedah dengan data morfometrik. Teknik pengukuran telinga palsu terakhir untuk mengesahkan keputusan yang diperolehi berbanding nilai daripada data morfometrik dilakukan secara digital menggunakan perisian. Kajian

morfometrik dijalankan ke atas 68 sampel telinga normal, kiri dan kanan dengan 15 parameter dikaji. Data diambil daripada *CT scan* kemudian di tukar kepada bentuk 3 dimensi menggunakan pilihan *soft tissue yang* terdapat dalam perisisan *MIMICS*. Teknik *mirror image* digunakan untuk membaiki semula telinga yang hilang, kemudian menghasilkan model 3D menggunakan teknologi *Sterelitography (SLA)*. Model 3D tersebut akan menjadi *master pattern* untuk menghasilkan telinga dengan kaedah *vacuum casting*.

Analisa morfometrik memberikan nilai purata dan sisihan piawai untuk panjang dan lebar telinga, panjang dan tinggi tragus, panjang sisipan telinga, panjang dan luas *lobular* dan *conchal*, *protrusion* pada level *superaurale* dan *tragal* dan juga sudut condong and sudut simetri. Kajian ini juga menunjukkan bahawa terdapat perbezaan yang signifikan antara kaedah tradisional dan kaedah terbantu komputer. Kaedah baru ini menunjukkan terdapat penjimatan daripada segi masa semasa proses rekabentuk dan fabrikasi dan juga menunjukkan peningkatan daripada segi ketepatan dan memenuhi tuntutan nilai-nilai estetik.

Morphometric Analysis and Fabrication of Prosthetic Ear Using CAD/CAM and Additive Manufacturing Technologies

ABSTRACT

Prosthetic ear rehabilitation is one of the treatments for auricular defect. Current practice by surgeon require patient to go for osseointegrated craniofacial implant surgery for retention of the prosthetic ear. Traditionally, the wax pattern was created from the impression taken from patient and the final prosthesis is processed with silicone material. This conventional method has always been time consuming, massive work and caused discomfort to patient. Moreover the accuracy of the final prosthetic sometimes was not satisfied. Impression technique play a vital role in determining accurate reproduction of affected and unaffected ears, orientation of the ear during wax try in and fabrication of ear prostheses. Hence, the ear anthropometric data is important to determine the correct orientation and position of the prosthetic ear.

This paper aims to provide morphometric data of a few standard ear parameters for Kelantanese and also describes a novel method of design and fabricating the prosthetic ear applying CAD/CAM and additive manufacturing technologies. A clinical study is done onto a patient in HUSM and comparison is made between traditional method and the new approach using computer aided technology. Study also validates the prosthetic ear obtained from both techniques with the morphometric data. The measurement technique of the final prosthetic ear to validate the result with regards to the morphometric data was done digitally using software. Morphometric study was conducted on 68 samples of normal ear for both

left and right with 15 parameters measured. Data was retrieved from CT scan and convert to 3D image using soft tissue development. Mirror image technique was applied to reconstruct the missing ear, and then fabricate the 3D model of the prosthetic ear using Stereolitography (SLA) technology. The 3D model will become the master mold to produce the final prosthetic ear using vacuum casting technology.

Morphometric analysis gave the mean and standard deviation values for auricular length and width, length and height of tragus, insertion length of auricle, length and width of lobular and conchal, protusion at superaurale and tragal level as well as the inclination and symmetrical angle. While study also illustrates that there is significant different between traditional and computer aided approach. The new method shows time reduction during design and fabrication stage and also show improvement in accuracy and aesthetic appearance.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Knowledge of the normal ear morphology is important in the treatment and management of variety of congenital deformities such as hemifacial microsomia, Tessier's facial cleft, microtia, etc. Also, its subtle structures convey signs of age, gender and aesthetic appearance.

Reisberg et. al (2003) has reported the importance of ear rehabilitation for facial aesthetic. Previous methods applying hand sculpturing, impression of similar ear for mirror imaging and wax modeling for ear reconstruction were applied. However, these traditional methods faces a lot of challenges in producing the correct anatomic morphology, time consuming and involved massive laboratory work. Moreover, the impression technique causes deformation and discomfort to the patient. Hence, its also contribute to inaccuracy in producing the prosthetic ear.

Coward et al (2007) has utilized a technique using stereo photogrammetric imaging to produce accurate ear prosthesis. Result from this study indicate that stereo photogrammetric showed some significant errors in their result. This could be due to limitation of locating anatomical landmarks especially bony landmarks. Furthermore, another method applying laser scanner have certain disadvantages such as high cost and need proper training (Ciocca et al, 2004).

These multi modality imaging techniques play an important role in data capturing. However, not many studies utilized computed tomography scan (CT scan) data for ear reconstructions applying computer reconstruction algorithm. With the marriage

of computer imaging technology and advanced manufacturing, recent studies indicate that computer aided design and computer aided manufacturing (CAD/CAM) can overcome the above problems (Jiao et al, 2004, Karatas et al,2011). Therefore, the aim of this research is to utilize this technologies of medical imaging and additive manufacturing to custom fabricate ear prosthetic for ear reconstruction and rehabilitation.

1.2 Problem Statement

Several studies have been done to study the anthropometric data of auricle for several ethnic groups, but none has been done in Malaysia. It is important to have prior knowledge of average values of each parameter and use these values to help in constructing prosthesis with the appropriate size and shape. Direct measurement technique to capture the ear dimension applied in many studies required the sample to be present during the measurement procedure. This limits the measurer to have limited landmarks location. And also difficulties in locating the landmarks point.

Current method applied in HUSM totally depends on the artistic skill of the operator. The mirror image technique applied to obtain the reconstructed ear from the normal ear sometimes is not accurate in the sense that errors may occur at any one of many stages during production. The most challenging procedure is to sculpturing the wax ear cast where the output will determine the patient aesthetic satisfaction. It takes 2-3 weeks to finish the sculpturing stage.

1.3 Justification of the Study

- The knowledge of the morphometric data of auricle that tailored to the Malaysian population is important for surgeon to rejuvenating the prosthetic ear.
- The images data taken from CT scan can be use to create 3D image and locate the landmarks to measure the parameters of the auricle.
- The integration of computer aided design and additive manufacturing technologies can simplify and improve the fabrication of prosthetic ear.

1.4 Objective of the Study

The objectives of this research are:

1. To measure and provide morphometric database of the normal ear for clinical application based on CT.
2. To compare and validate the database obtained from (1) applying CAD/CAM and fabricated using additive manufacturing.
3. To apply and evaluate the prosthetic ear obtained in (2) through a case clinically study compare with result obtained from the data as in (1).

1.5 Hypotheses

There is no significant difference between the normal ear morphology measure from CT scan and prosthetic ear obtained from CAD/CAM.

CHAPTER 2

LITERATURE REVIEW

2.1 Ear Morphology

The morphology of the ear is highly complex. Generally, the human ear is divided into external, middle and internal parts. As for this study, the area of interest is the external ear. So, the detail explanation throughout this article will explain the external ear structure.

The auricle (or pinna) and the external acoustic meatus form the external ear. The auricle is an external, lateral paired structure. Its function is to capture and transmit sound to the external acoustic meatus. Figure 2.1 show the anterior surface of the auricle (or the pinna) of the ear.

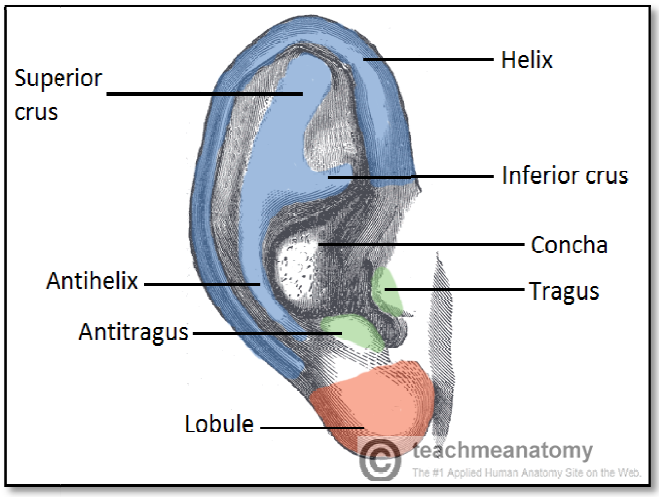


Figure 2.1: The anterior surface of the auricle (or pinna) of the ear.

Most of the auricle has a cartilaginous framework, with the lobule the only part not supported by cartilage. The outer curvature of the ear is called the helix. Moving inwards, there is another curved elevation, which is parallel to the helix – this is known as the antihelix. The antihelix divides into two cura – the inferoanterior crus, and the super posterior crus.

In the middle of the auricle is a hollow depression, called the concha of auricle. It continues into the skull as the external acoustic meatus. The concha acts to direct sound into the external acoustic meatus. Immediately anterior to the start of the external acoustic meatus is an elevation of tissue – the tragus. Opposite the tragus is the antitragus. Basically, each anthropometric study of auricle conducted based on these important parts of auricle. The indices of auricle, tragus, lobular and conchal are the most important parameter to be calculated in many studies.

According to Ekanem (2010), the lateral surface of the pinna is irregularly concave, faces slightly forward and displays numerous eminences and depressions. A few anthropometrical studies have been conducted to reveal the auricle morphometric data of different ethnic group. For example, Ekanam (2010) study on pinna (auricle) among Nigerian adult, Wang et al. (2011) study on Han Chinese population. Sforza et al. (2009) provide information about normal ear morphology symmetrical and growth changes in normal Italian Caucasian. In another study, Kalcioglu et al. (2003) revealed the anthropometric growth of auricular from birth to 18 years old in Turkish population.

These studies related to ear dimensions and ear growth pattern suggest the importance of diagnosis and management of variety of congenital malformations or syndromes. Furthermore, these results were utilized in industry that manufactures instrument such as hearing aid, earphone etc etc. Its subtle structures also could convey signs of aging and gender differences which are not easily noticeable (Azaria et al, 2003). In another study, Sullivan and colleague Brucker et al (2003) emphasized the importance of detail information required for ear reconstruction.

2.2 3-Dimensional (3D) Imaging Technique in Craniofacial

Many of the existing anthropometry data on the auricle have been obtained from direct measurement techniques, to assess the dimensions, locations, inclination and level of typical ear. Direct measurement technique meaning that the measurement procedure requires the subject to be presence and vernier caliper or other measuring devices used during measurement (Purkait, 2012, Ekanam, 2010).

However, in 2009, Sforza (2009) in his study utilized a new method to capture 3 dimensional image of the subject using 3-dimensional computerized electromagnetic digitizer. While recent study by Sencimen (2012) and Wang et al (2010) used CT image data to visualize the 3D image and performed the morphometric analysis as well. With this 3 dimensional image, the quantitative assessment of the dimensions of human facial soft tissue structures such as eyes, nose, mouth and lips, chin and ears can easily be captured and used for multiple purposes of study or in research activities. This 3 dimensional image technology has become an important technique in medical field especially in craniofacial reconstruction and prosthetic rehabilitation to visualize the respective area of interest and planning for further treatment.

There are varieties of methods to generate 3 dimensional facial images such as laser scans, stereo-photogrammetry, infrared imaging and even computer tomograhic (CT). Each of these methods contains inherent limitations and such no systems are in common in clinical use. Each method requires specific instruments and handled by trained operator. Sforza (2006) has explained the instruments used in 3 dimensional digital morphology. The instruments available for computerized soft tissue 3 dimensional facial anthropometry can be divided into two main categories: optical, non-contact digitizers (laser scanners, 3D range-cameras,

optoelectronic instruments, stereophotogrammetry, Moire topography) and contact instruments (electromagnetic and electromechanical digitizers, ultrasound probes). Both kinds of instruments are non-invasive, not potentially harmful and do not provoke pain to be used to human directly. In this research, the technique use to capture the 3D image for study is by implementing the non-contact instrument, thus the entire discussion in this literature will mainly focus on the technology available within the area.

The optical instruments can be used for a fast analysis of facial surface, thus providing data on facial surface area and estimates of facial volume, and indirect anthropometric assessment. The principal instruments are laser scanner and stereophotogrammetric system.

2.2.1 Laser Scanning

3D Laser Scanning or 3D Laser Scanners can generally be categorized into three main categories - laser triangulation, time of flight and phase shift. These laser scanning techniques are typically used independently but can also be used in combination to create a more versatile scanning system. There are also numerous other laser scanning technologies that are hybrids and/or combinations of other 3D scanning technologies such as accordion fringe interferometry or conoscopic holography.

- Laser triangulation is accomplished by projecting a laser line or point onto an object and then capturing its reflection with a sensor located at a known distance from the laser's source. The resulting reflection angle can be interpreted to yield 3D measurements of the part.

- Time of flight laser scanners emit a pulse of laser light that is reflected off of the object to be scanned. The resulting reflection is detected with a sensor and the time that elapses between emission and detection yields the distance to the object since the speed of the laser light is precisely known.
- Phase shift laser scanners work by comparing the phase shift in the reflected laser light to a standard phase, which is also captured for comparison. This is similar to time of flight detection except that the phase of the reflected laser light further refines the distance detection, similar to the vernier scale on a caliper.

Z.Majid (2008) in his study reported that for short distance scanning case (like scanning human face), most of the 3D laser scanners in the market was design and built using the triangulation method. The triangulation method is based on triangle concept that linked the laser device, charge couple device (CCD) camera and the scanning object. Figure 2.2 shows the Minolta VI-910 3D laser scanner that was used in his study to develop craniofacial spatial data.

Figure 2.2: The Minolta VI-910 3D laser scanning system. *[From Z.Majid (2008), Figure 7, page 807, with permission)*

The laser scanners can produce a detailed model but the digitization process requires the subject to remain still for a period of several seconds to a minute or more while the scanner head revolves around the subject's head. Accuracy and resolution are reported between 0.5mm and 1mm, and approximately 30s are necessary to complete scan (Sforza, 2006). In addition, the output can be noisy thus requiring additional processing to treat noise, outliner, and holes. Weinberg and Kolar (2005) reported in their study that not all facial surfaces can be scanned, and the most lateral parts of the face (namely the ears) may not be well digitally well produced. Also, Z.Majid (2005) mentioned in his study that shadows, local facial characteristics (hairs, nevi), as well as dark complexion may obtrude the digitization, and motion artifacts can occur during the scan. The data processing method from the laser scanning process involved six common processes which is filtering noise,

initial registration and fine registration of the two shells, merging, holes filling and smoothing (Figure 2.3). The common processing steps mentioned above was offered by most of the laser scanning data processing software such as RapidForm 2004 (INUS Technology, Korea) and Polygon Editing Tools (PET) software (Konica Minolta, Japan).

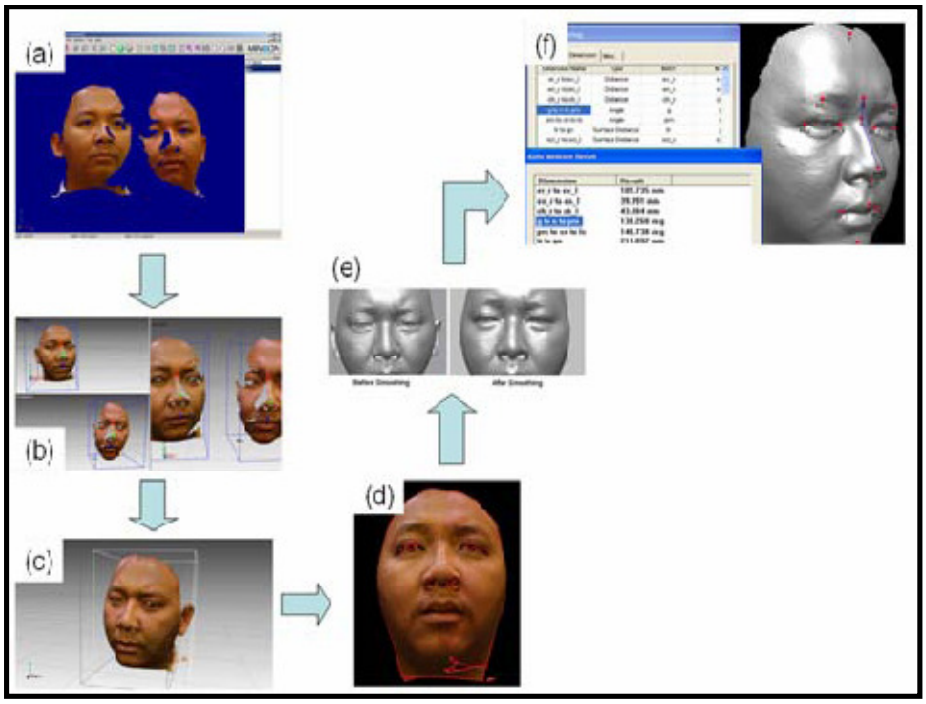


Figure 2.3: Pre and post processing of 3D laser scanning datasets – (a) raw datasets, (b) registration process, (c) merging process, (d) filling holes, (e) smoothing process and (f) measurement of craniofacial landmarks. *[From Z.Majid (2008), Figure 21, page 811, with permission)*

2.2.2 Stereo-photogrammetry

Photogrammetry is a process of obtaining quantitative three-dimensional information about the geometry of an object or surface through the use of photographs. The principles behind photogrammetry are to take multiple images of objects and manually or automatically reference common points in each photograph. Points can be added automatically or manually to create 3D measurements of the

desired elements of the part. This technology is often used with other 3D scanning technology to provide full surface measurement of parts and to retain tight tolerance over large areas.

In stereo-photogrammetry, a light source illuminates the face, and two or more coordinated cameras record the images from different points of view (Heike et al, 2010). A computerized stereoscopic reconstruction is then obtained (Fig 2.4). The accuracy and resolution are around 0.5mm and 2ms and can be sufficient for facial scan. However, surface artifacts and uneven surface coverage are the limitations for this technology (Sforza, 2006). Carrie et al.(2010) also reported that most digital stereophotogrammetry systems have difficulty in capturing hair, thus result in substantial loss of surface data on head and face. The forehead and the ears are the region most vulnerable to interference from scalp hair (Figure 2.5).

Figure 2.4: Wireframe range models of a female face obtained by stereophotogrammetry *[From Sforza (2006), Fig 2, pg 104, with permission]*

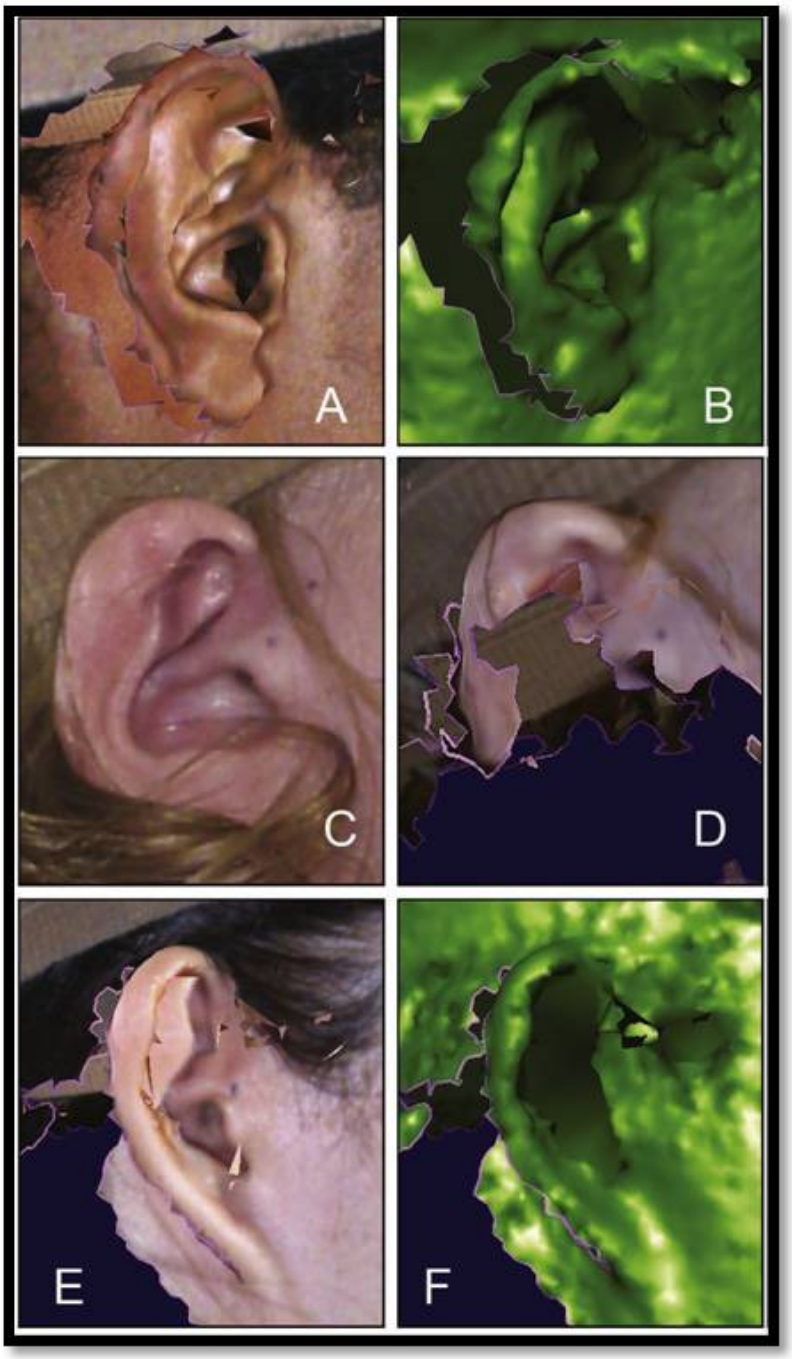


Figure 2.5: Example of inadequate surface coverage. *[From Carrie et.al (2010), Figure 5, page 6, Open access)*

In the recent study by Fourie et al (2010), 3D stereo-photogrammetry has been utilized to capture the image and quantify the craniofacial surface morphology. The advantages of 3D stereo-photogrammetry are near instantaneous image capture (in

the order of 1.5ms) which minimizes motion artifact, provision of archived image for subsequent and repeated analyses, collection of data points in 3D coordinate format for subsequent morphometric studies, and high resolution colour representation. Furthermore, software tools are available that allow the user to manipulate the image to facilitate identification of landmarks and calculate anthropometric measurements and measuring volumes. A wide variety of commercially available digital 3D photogrammetric devices have become available, many of which differ considerably in terms of cost, capture method, imaging hardware and software. For examples, the Di3D system-Dimensional Imaging, Hillington Park Glasglow, UK and 3dMDcranial System as shown in Figure 2.6.

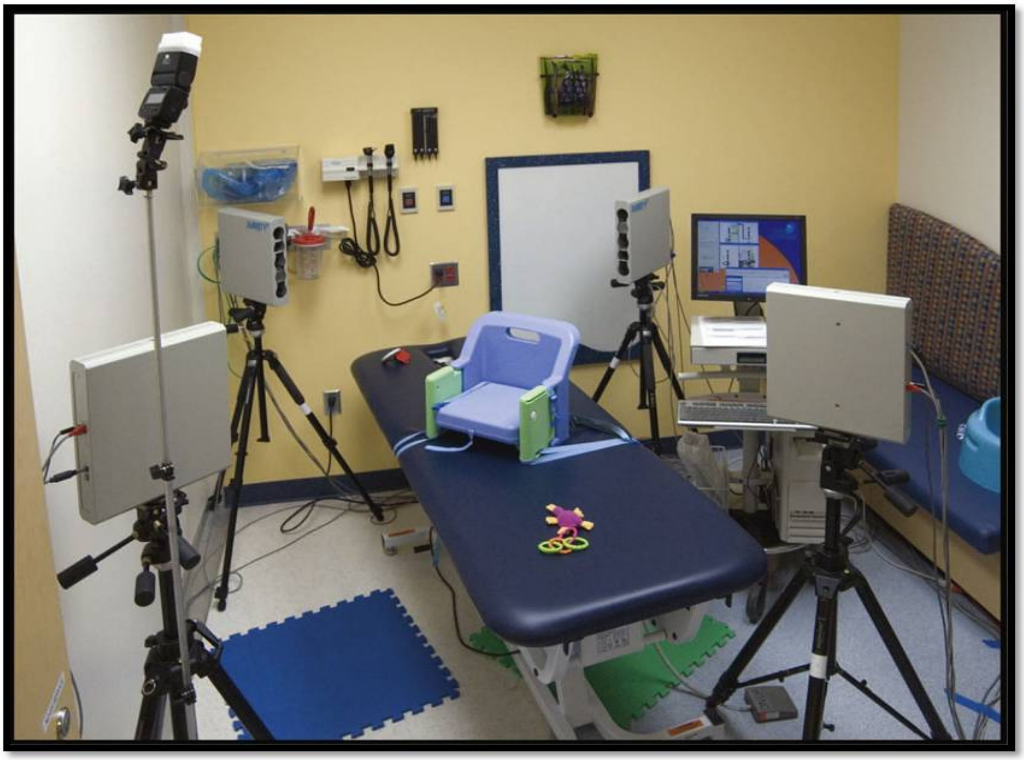


Figure 2.6: An example of a 3D stereophotogrammetry system (3dMDcranial System) in clinical research setting *[From Fourie (2010), Figure 3, page 4, Open access)*

2.2.3 Computerized Tomography (CT) scanning

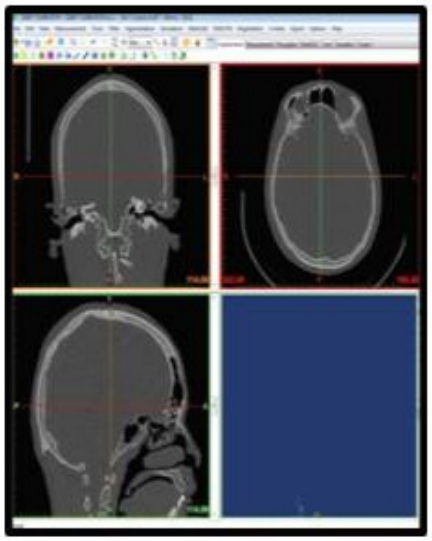
CT scan is a useful tool for assisting diagnosis in medicine. It is very useful to get a very detailed 3D image of certain parts of the body, such as soft tissues, the pelvis, blood vessels, the lungs, the brain, abdomen, and bones. Bone imaging is important in the presurgical operation of auricular area where surgeon can determine the best position to place the implant. CT scan with 3 dimensional reconstructions reveals adequate sites for bone implants where usually implants are placed into the mastoid bone. Giot et al (2011) reported in his study the use of CT scan to examine the mastoid bone for bone anchored auricular prosthesis.

The CT scanner uses digital geometry processing to generate a 3-dimensional (3D) image of the inside of an object. The 3D image is made after many 2-dimensional (2D) X-ray images are taken around a single axis of rotation - in other words, many pictures of the same area are taken from many angles and then placed together to produce a 3D image. Inside the CT scanner there is an X-ray detector which can see hundreds of different levels of density. It can see tissues inside a solid organ. This data is transmitted to a computer, which builds up a 3D cross-sectional picture of the part of the body and displays it on the screen. Figure 2.7 shows the CT imaging suite available at Radiology Department, Hospital University Science Malaysia (HUSM).

Figure 2.7: The CT imaging suite provided at Radiology Department, HUSM.

However, the ability to perform the 3D image requires sophisticated medical imaging software to do the translation. CT gives stacks of 2D X-ray images in dicom format, and the software will convert the images into 3D model. There are a few medical softwares in the market that specifically process the medical image data (CT, MRI, 3D ultra sound, CBCT) and convert it to 3D model such as MIMICS (from Materialise, Belgium), 3D Slicer, Simpleware, Amira and also Invesalius software. Figure 2.8 shows the workflow from imaging data to 3D model.

A



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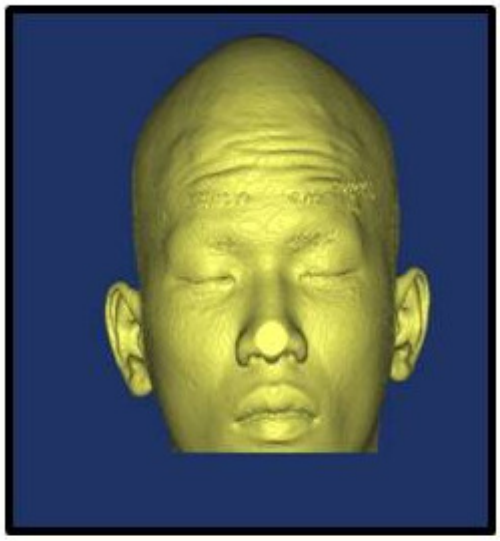
C



D

A: Patient with CT scan procedure
B: 2D view from CT scan image data
C: Stacked scan image data slices
D: 3D view from soft tissue

Figure 2.8: Process workflow from CT scan imaging to 3D model

The beauty of this technique is that, the complex distortion of the natural ear can be measured easily and the difficulty in locating landmarks may be overcome. Wang et al., 2011 utilize the medical image from CT scan to perform the morphometric measurement for human ear. The data can also be review many times as required without need of the person presence. With the appropriate normative data obtain from this technique surgeon can have better define approach to ear reconstruction.

2.3 Prosthetic Ear Fabrication

Replacement of an ear can be done by surgical reconstruction or auricular prosthesis. By surgical reconstruction, patient has to undergo multiple surgeries over a period of time. In some cases, surgical reconstruction is not possible. In the case of congenitally missing ear, surgical reconstruction is most common but the result may not be acceptable to the patient (Reisberg et al., 2003). Prosthetic rehabilitation is a viable alternative to surgical reconstruction.

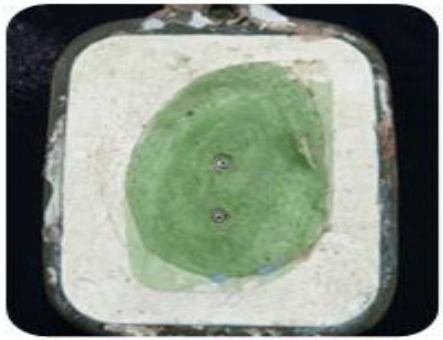
Ear prosthesis now a day is made of medical grade silicon rubber and the shape and color are customized for each patient. In the past, these prostheses have been retained with skin adhesives which contribute to several problems. Its application may be messy and time consuming. Therefore, implant retention has been used. This procedure is called Osseo integrated implant whereby patient needs to go for a surgery to bond the implants with the bone to provide a stable attachment of the prosthesis (Reisberg et al., 2003, Sencimen, 2012). During this procedure, abutments can be placed onto the osseointegrated screws that support the bars, clips or magnets. Thus support the prosthesis.

The prosthetic ear fabrication performed by a maxillofacial technologist or anaplastologist in a laboratory. The conventional method of fabricating ear

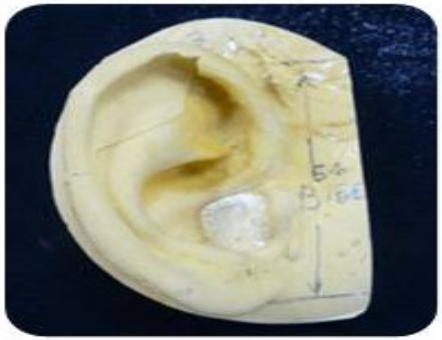
prosthesis relies on the artistry and availability of the anaplastologist (Karatas, 2011). Several of these procedures are time consuming and require the patient to be present for an extended period of time. Basically, the conventional method of fabricating the ear prosthesis involves:

1. Making impression to duplicate affected area and replicate the unaffected area to determine the correct geometry and position of the prosthesis
2. Creating a clay or wax sculpture of the future prosthesis
3. Silicone injection with the color in to the working mold to get the prosthesis
4. Finishing – trim the prosthetic to obtain final end product and also recoloring if applicable. (Liacouras et al. 2011).

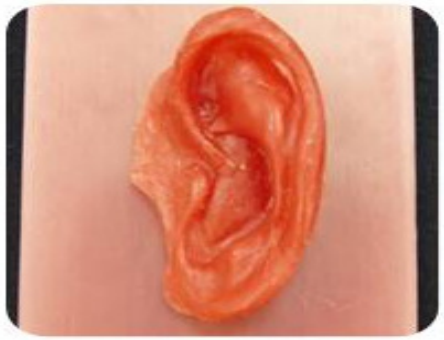
Figure 2.9 illustrates the overall process of fabricating the ear prosthesis.



1. Mold from defective ear impression



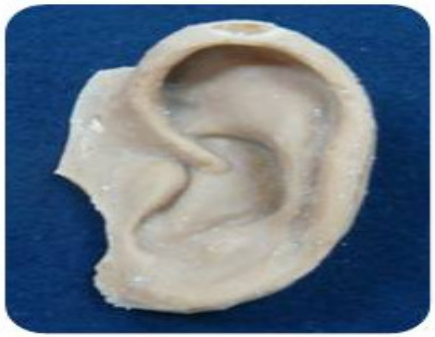
2. Measurement from normal ear



3. Wax sculpture

4. Positive mold making with wax sculptured inside

5. Dewax



6. Prosthetic ear

Figure 2.9: Conventional method of prosthetic ear fabrication

2.4 CAD/CAM and Additive Manufacturing (AM) for Prosthetic Ear Fabrication

CAD/CAM is an acronym for Computer-Aided Design and Computer-Aided Manufacturing. These technologies have been used extremely in engineering field because of their high precision and accuracy. These technologies have been first introduced to dental field by Mormann & Brandestinni from Germany in 1989 and it started being used in dental laboratories to design and manufacture various types of dental restoration and prostheses (Amit et al., 2014). Nowadays, it is widely used in all branches of prosthodontic, orthopaedic and even in cardiovascular.

While additive manufacturing (AM) or formerly known as rapid prototyping technology is kind of technology that can develop models and prototype automatically from CAD data, transform them into thin, virtual, horizontal cross sections and then creates each cross section in physical space, one after the next until the model finished without human intervention or tooling devices. It is called "additive" because it combines layers of wax or plastic to create solid object. It contrast, most machining processes such as milling, grinding, drilling etc are subtractive process that remove material from solid block. Additive manufacturing nature's allows it to create objects with complicated internal features that cannot be manufactured by other means.

At least six different additive manufacturing techniques are commercially available, each with unique strengths. Because additive manufacturing technologies are being increasingly used in non-prototyping applications, the technique are often collectively referred to as solid free-form fabrication, computer automated manufacturing or layered manufacturing. Although several additive manufacturing techniques exist, all employ the same basic five step processes which are:

1. Creating a CAD model of the design
2. convert the CAD data to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer a top another
5. Clean and finish the part.

A large number of competing technologies are available in the marketplace. As all are additive technologies, their main differences are found in the way layers are built to create parts. Some are melting or softening material to produce the layers (SLS, FDM) where others are laying liquid materials thermosets that are cured with different technologies. In the case of lamination systems, thin layers are cut to shape and joined together. As in this research work, SLA technology will be use to fabricate the prosthetic ear mold and detail explanation of this technology will be describe in the literature.

2.4.1 Application of CAD/CAM in Prosthetic Ear

Study conducted by Jiao et al. reported that fabrication of ear prostheses using CAD/CAM are advantageous because a highly qualified technician is not necessary to sculpture an ear in wax. The procedure can be carried out in a computer and patient can visualize the result at the screen before fabrication. Subburaj et al.(2007), also demonstrated the method of fabricating the auricular prosthesis using CAD/CAM and rapid prototyping technologies. The result showed that the computer aided method gave a higher level of accuracy in terms of shape, size and position of the prosthesis, and significantly shorter lead time compared to conventional technique. Karatas et .al (2011) also reported that the prosthesis produced by CAD/CAM techniques was more realistic and maintain good facial harmony.

2.4.2 Stereolitography (SLA) Technology Principle

Currently, there are various numbers of additive manufacturing technologies available in the market, based on special sintering, layering or deposition methods. Some of the famous technologies are Stereolitographic (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), 3D Printing. Among of these technologies, SLA is the leading technology with over 500 SLA machine installed worldwide (McGurk et.al, 1997). It's developed by 3-D Systems Inc, of Valencia, CA. The SLA 7000 system is two times faster, on average, than the next fastest solid imaging system from 3D systems (Figure 2.10). Its system's 0.0254 mm layer thickness yields a smooth finish that result in far less post-processing time.

Figure 2.10: SLA 700 machines with part produced – available at SIRIM BERHAD.

Its basic principle technology employs a vat of liquid ultraviolet curable photopolymer resin and an ultraviolet laser to build parts layers one at a time. Fig 2.11 shows the schematic diagram of SLA process. For each layer, the laser beam traces a cross –section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet laser light cures and solidifies the pattern traced on the resin and joints it to the layer below. After the pattern has been traced, the SLA's elevator platform descends by a distance equal to the thickness of a single layer, typically 0.05mm to 0.15mm. Then, a resin filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, joining the previous layer. A complete 3D part is

formed by this process. After being built, parts are immersed in a chemical bath in order to be cleaned of excess resin and are subsequently cured in an ultraviolet oven.

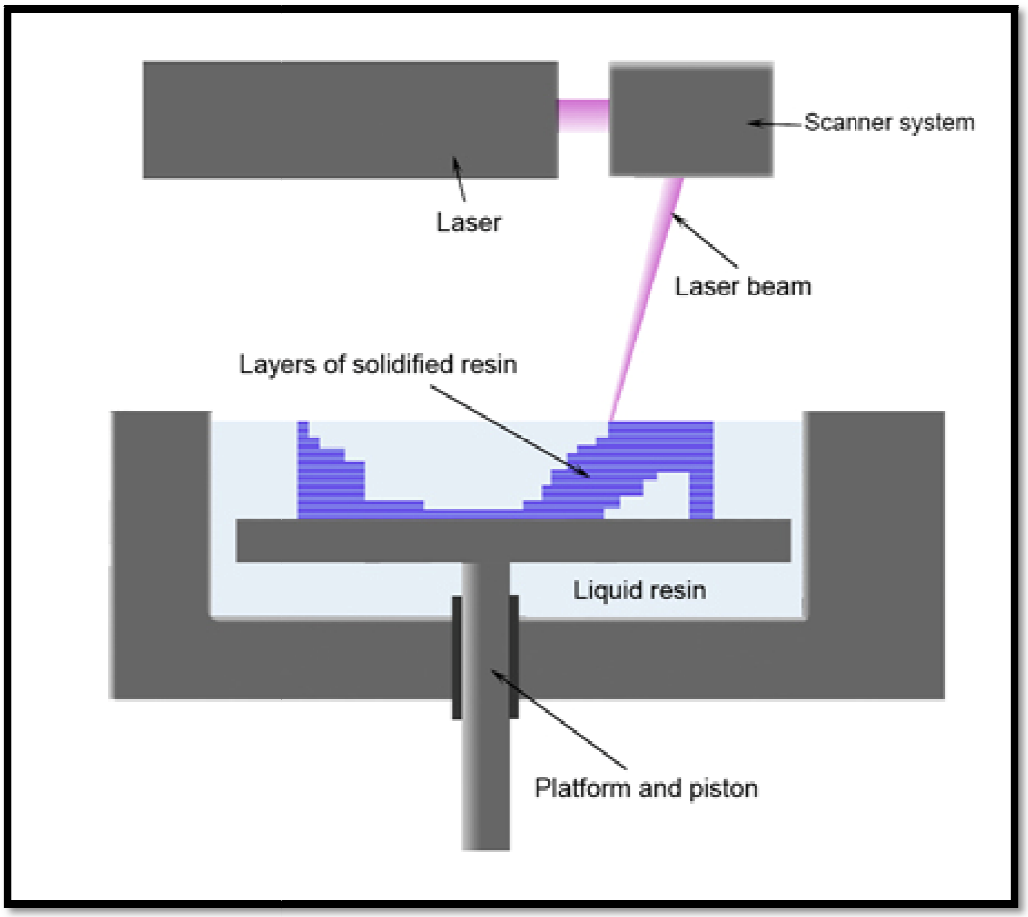


Figure 2.11: Schematic diagram of SLA technology

2.4.3 Additive Manufacturing Application in Prosthetic Ear

Additive Manufacturing (AM) technology has been introduced in the biomedical field for fabrication of models to ease surgical planning and simulation in implantology, neurosurgery and orthopaedics, as well as for the fabrication of maxillofacial prostheses (Goiato et al. 2011). In the case of prosthetic ear, 3D model developed through AM technology become a surgical template to guide surgeon in planning the prosthetic ear surgery to ensure proper position and orientation of the implants (El Charkawi et al., 2012). Nanda et al., (2011) also